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Traffic Forecasts Ignoring Induced Demand: a Shaky Fundament for Cost-Benefit Analyses

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Although the phenomenon of induced traffic has been theorized for more than 60 years and is now widely accepted among transport researchers, the traffic-generating effects of road capacity expansion are still often neglected in transport modelling. Such omission can lead to serious bias in the assessments of environmental impacts as well as the economic viability of proposed road projects, especially in situations where there is a latent demand for more road capacity. This has been illustrated in the present paper by an assessment of travel time savings, environmental impacts and the economic performance of a proposed road project in Copenhagen with and without short-term induced traffic included in the transport model. The available transport model was not able to include long-term induced traffic resulting from changes in land use and in the level of service of public transport. Even though the model calculations included only a part of the induced traffic, the difference in cost-benefit results compared to the model excluding all induced traffic was substantial. The results show lower travel time savings, more adverse environmental impacts and a considerably lower benefit-cost ratio when induced traffic is partly accounted for than when it is ignored. By exaggerating the economic benefits of road capacity increase and underestimating its negative effects, omission of induced traffic can result in over-allocation of public money on road construction and correspondingly less focus on other ways of dealing with congestion and environmental problems in urban areas.

Keywords: Traffic models, Induced traffic, Travel time savings, Cost-Benefit Analysis, Benefit overestimation

1. Introduction

The aim of the present article is to illustrate how common appraisal techniques can be, and often are, depicting benefits and drawbacks of proposed transport infrastructure investments in a

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distorted way. Cost-benefit analysis (CBA) is typically the most common form of appraisal technique for such projects (Hayashi and Morisugi, 2000; Mackie 2010; Odgaard, Kelly, and Laird, 2005).

Within the community of scholars and practitioners dealing with CBAs of transport infrastructure projects, there is widespread acknowledgment of a number of flaws in the existing use of this method (Ackerman and Heinzerling, 2004; Mackie, 2010; Næss, 2006; Salling and Banister, 2009, van Wee, 2011). In a recent seminar⁴ on the use of CBAs in the transport sector, virtually all presentations highlighted problems associated with the method and its use in planning and decision-making, including the valuation of traffic time, environmental pollution, deaths and injuries from traffic accidents, and not the least the forecasts of future traffic volumes and time savings (Debenardi, Grimaldi, and Beria, 2011; Mackie, 2010). Estimates of construction costs and traffic demand have also often turned out to be highly inaccurate and most often too optimistic (Flyvbjerg, Bruzelius, and Rothengatter 2003; Holm 2000; National Audit Office 2007; Odeck 2004; Parthasarathi and Levinson 2010; Welde and Odeck 2011). Yet, there was the almost unanimous opinion of the participants of this seminar that the solution to these problems was to refine the CBA method and its usage, not to shift to a different way of evaluating project proposals. Apparently, the problem is not that the medicine has been misplaced, but that the dose has not been appropriate.

For road projects, the accuracy of traffic demand forecasts are crucial to the validity of any subsequent impact assessments, whether this is in the form of CBAs or other appraisal techniques. These forecasts form the basis for estimates for a wide range of impact factors, including time savings, emissions, and noise. Since traffic demand seems to be underestimated for road projects on average (Flyvbjerg, Bruzelius, and Rothengatter, 2003; Holm 2000; Næss, Flyvbjerg, and Buhl, 2006; Parthasarathi and Levinson, 2010; Rodier, 2004; Welde and Odeck, 2011), one might assume that this would cause benefits to be underestimated as well. However, underestimating the demand for road traffic also means that the expected time saving benefits might not materialize due to additional traffic, since demand could become so high on the new infrastructure that congestion occurs. It is this latter effect that will be the focus of the present article.

For transport projects there is a range of impact factors that lend themselves to appraisal via CBA, but in practice only a few of them have any noteworthy impact on monetized appraisal results. This is especially the case of projects concerned with expansion of road capacity. Usually, travel time savings make up most of the expected benefits for new road projects (Banister 2008; Mackie, Jara-Diaz, and Fowkes 2001). For example, in the CBA of a recent proposal for a new motorway in Denmark⁵, travel time savings amount to 84 % of the total benefits on average. The price and volume of time savings are thus without comparison the most decisive benefit parameters in a CBA for road capacity expansion. Although the monetary values given to time savings are contested and represent an important source of inexactness, this will not be dealt with in the present study. Instead we shall focus on the second source of uncertainty, which is the expected savings in terms of reduced travel times for drivers as a result of added capacity. More precisely, the purpose of the paper is to illuminate how the neglect or underestimation of induced traffic can seriously distort the results of cost-benefit analyses of road projects in congested urban situations.

The research on which the paper is based has been carried out as part of a larger research project (UNITE) addressing uncertainties in transport model evaluation (Nielsen, 2008). In the present paper, model simulations of a road project in Copenhagen with and without inclusion of induced

⁴ Contemporary Issues in CBA in the Transport Sector, Royal Institute of Technology, Stockholm, March 16, 2011.

⁵ An additional highway crossing over the Limfjord sound near the city of Aalborg in the northern part of Denmark.

traffic is a main source of evidence. In addition, similar, but less in-depth simulations have been carried out for the network of major roads in Greater Oslo, as well as for a planned motorway in a less congested part of Copenhagen Metropolitan area. In the discussion of the results, we will also draw on other empirical data collected in the UNITE project, in particular questionnaire survey data and in-depth research interviews with modellers, transport planners and politicians. The empirical context of the article is the Scandinavian countries, particularly Denmark, but we think the conclusions are relevant also in a wider international context insofar as induced traffic is not fully taken into account in transport modelling practice.

2. The effect of induced traffic

Several explanations have been offered for the observed bias in forecasts of both costs and benefits. Some authors suggest that cognitive biases could be the cause of this (Armor and Taylor, 2002; Kirkebøen, 2009; Lovallo and Kahneman, 2003; Weinstein, 1980) while others look to strategic misrepresentation as an explanation (Flyvbjerg, 2007; Jones and Euske, 1991; Kain, 1990; Wachs, 1989). In the present article we shall focus on how potential technical deficiencies in the modelling of traffic demand can be a cause of bias. However, it should be noted that technical deficiencies are not a disjoint category of explanation, but could just as well be a result of cognitive bias or strategic misrepresentation.

In the case of forecasting traffic demand for road projects, omission of induced traffic could be a possible explanation why traffic demand appears to be systematically underestimated. Road improvement generally tends to increase overall traffic volumes due to lower cost of traffic in the form of less time spent to reach a given destination. The effect of induced traffic is now widely accepted among transport researchers (American Association of State Highway Officials, 1957; Downs, 1962; Goodwin, 1996; Growther, 1963; Hills, 1996; Litman and Colman, 2001; Mogridge, 1990; Newman and Kenworthy, 1989; Nicolaisen and Næss, 2011; Noland and Lem, 2002; Næss, Mogridge, and Sandberg, 2001; Overgaard, 1966; SACTRA, 1994; Thomson, 1977). In line with theories of transport economics and transport geography, and a number of empirical investigations in various countries, road development facilitating higher traffic speeds will result in generated and induced traffic by influencing the following six parameters:

- Route choice
- Peak hour traffic
- Modal split
- Overall transport volume
- Land use (long-term)
- Quality of public transport services (long-term)

Among these six effects, the four latter contribute to genuinely induced traffic (i.e. additional vehicle kilometres), whereas the two former contribute to relocation of existing traffic in time (e.g. between the rush-hour and other times of the day) and space (e.g. between different routes in the same transport corridor). To avoid confusion we do not refer to changes in the temporal or spatial distribution when using the term induced traffic, but are mainly concerned with the effects of parameters 3-6 in the case presented here. In the discussion in section 5 we shall, however, cover parameters 1 and 2 as well.

For road projects, the effect of induced traffic implies that traffic demand exceeds forecasts if these do not take this effect into account (or traffic is overestimated in the no-build alternative, see Næss (2011) for a discussion of this). One interpretation of this could be that more drivers benefit from the new capacity, and that the latent demand means the infrastructure investment

has been more feasible than expected. However, more traffic also causes higher environmental stress in the affected area, and if the traffic volume becomes large enough to have a detrimental effect on flow, there is also a loss of time saving benefits. The short-term effect of this is problematic for the situation immediately after the new capacity is opened, but the long-term effect from changes in land use, car ownership, and commute patterns are even more severe. It is possible to include the short-term effect of induced traffic in models, but often this is not done (Johnston and Ceerla, 1996; MOTOS, 2007; Nielsen and Fosgerau, 2005; Næss, 2011). Long-term effects are even more problematic to include, due to the inherent uncertainty associated with estimation of parameters that are dependent on a wide range of unknown factors.

In Denmark, only very few transport models currently in use take induced traffic into consideration. According to Nielsen and Fosgerau (2005), induced traffic has usually been underestimated or totally ignored in the forecasts made as preparation for decisions about larger Danish road projects in the past decades. The only exception is the so-called Ørestadens Trafik Model (OTM), which was originally developed to assess the demand for the Copenhagen metro project, opened in 2002. For most of the modelling work undertaken in Denmark in this period, induced traffic has thus usually been disregarded. According to the responsible parties in the Danish Road Directorate, the regional transport models have during the most recent years been adapted to account for induced traffic (UNITE, 2011a).

However, these model features are not always used in practice. For example, in a recent analysis of the impacts of adding motorway capacity to an existing bridge, a model that did not account for induced traffic was preferred over one that did, in spite of the latter being available⁶. The argument for not doing so seems to be a feeling that induced traffic does not cause significant growth in traffic, and that the effect on the CBA would be negligible even if it was taken into account. In a recent report by a government appointed commission on the need for future development of transport infrastructure in Denmark, the effect of congestion as a deterrent against further traffic growth in a given road network was disregarded in the transport model calculations (Danish National Infrastructure Commission, 2008). Traffic was therefore assumed to grow at a fixed rate, even in situations where driving speeds were predicted to be significantly reduced due to congestion. The identical traffic growth forecasts with and without capacity increases result in exaggerated assessments of the amount of congestion in the absence of new road construction. Since this document now serves as a reference for appraisal of transport infrastructure projects, such bias in the underlying assumptions distorts the entire appraisal system, and thus also the validity of any results it produces.

In Norway, induced traffic was generally ignored in the transport models used in transportation planning until the late 1990s. Since then, models recognizing that congestion reduces the attractiveness of car traffic have been developed, including two transport models (FREDRIK and RETRO) for the Oslo region (Minken, 2005). In Sweden, the national transport model SAMPERS has the possibility of including induced traffic. However, it is not always clear whether the actual modelling practice includes only traffic relocated from other roads or also increases in the traffic within the corridor as a whole (Jonsson et al., 2011), just as simpler approaches are common for smaller projects due to the resource intensity of a full SAMPERS model run (UNITE, 2011a). Among 48 respondents experienced with Swedish transport models, 67 % stated that they completely or partly agreed in the statement that transport models are poor at forecasting the effects of induced traffic. In Denmark and Norway, the corresponding shares were 52% and 48%, respectively (UNITE, 2011b).

Neglect of induced traffic appears to be commonplace in other European countries too. At least until a few years ago, induced traffic has usually been ignored or considerably underestimated in German transport modelling and planning (Marte, 2003). In a similar vein, Mackie (2010)

⁶ Interview with Henrik Nejst Jensen, Danish Road Directorate (September 2010)

mentions inadequate appraisal treatment of induced behaviours as a point of criticism frequently raised against CBA practice of transport infrastructure projects in the United Kingdom. According to the European MOTOS handbook on transport project evaluation, many transport models used in practice do not adequately account for induced traffic, and use of fixed matrices have traditionally been quite common (MOTOS 2007). All in all, it seems that induced traffic has traditionally been ignored in many transport models around Europe, and while some of the newer models in use have been adapted to account for this effect, they often do so inadequately or enjoy only limited usage. In the United States, federal clean air rules require induced traffic to be accounted for in metropolitan transportation models to evaluate the effects transport system changes have on vehicle emissions, but few models used in medium and small American cities are able to meet this requirement (Litman, 2011).

Figure 1 is adapted from Litman (2011), and illustrates how expected travel speeds are systematically overestimated when induced traffic is ignored. It is this effect that causes a distorted assessment of benefits in CBAs for road capacity expansion.

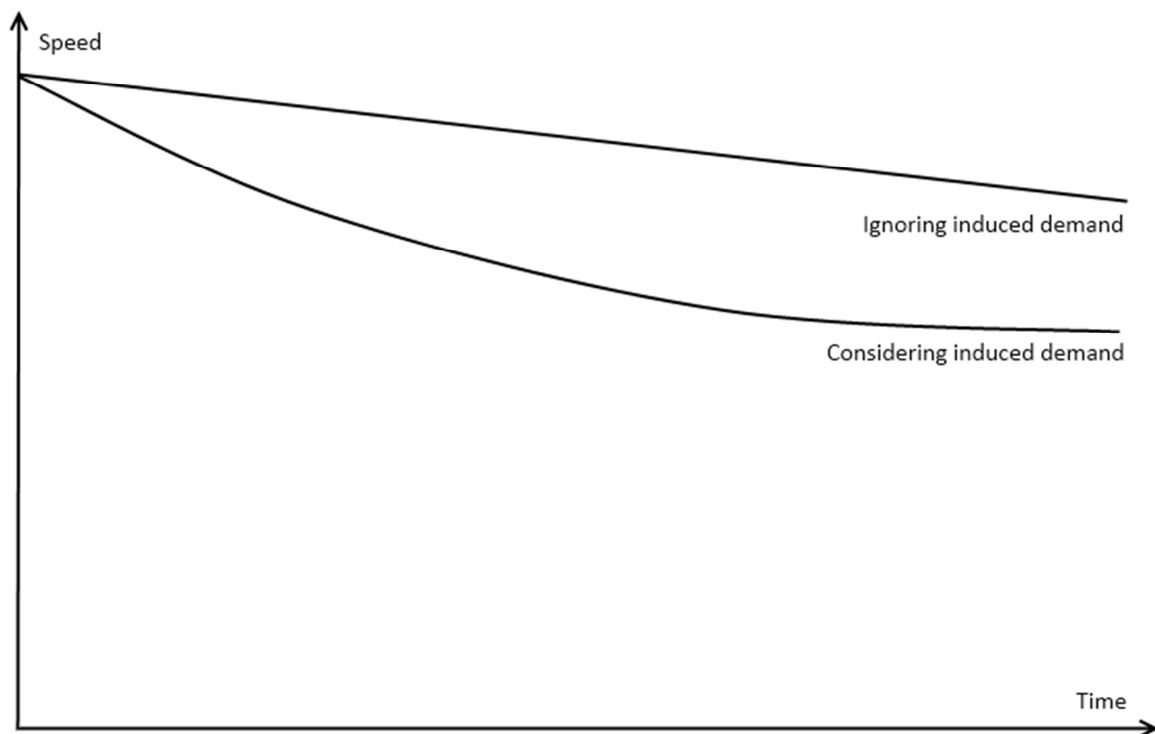


Figure 1. Projected average future traffic speeds, depending on whether or not induced traffic has been included in the forecasting model. Adapted from Litman (2011), p. 18.

The magnitude of induced traffic can be illustrated through the results of a model simulation for Greater Oslo in Norway. The transport model applied until recently for this region, FREDRIK, offered the opportunity of including induced traffic as well as omitting it. As part of a transport study for the Oslo Region, the need for additional road lanes resulting from a requirement for free-flowing traffic (i.e. no congestion) in a future 2030 situation was illustrated. A simulation specifically made as input for the present article was made with and without induced traffic taken into consideration. As shown in Figure 2, the estimated need for additional lanes is considerably higher when induced traffic is taken into consideration than in the simulation where induced traffic is ignored. The difference between the simulations with and without induced traffic varies from none to six additional lanes, depending on the position of the road in the entire road network.

Nielsen and Fosgerau (2005) illustrate how the effect can be problematic for assessment of time saving benefits, especially in the form of CBAs. Figure 3 is adopted from their work, and illustrates the supply curves with and without new capacity (do nothing vs. do something). As new capacity is introduced on the network the cost (time) of traffic decreases, and the equilibrium moves from X to Y, which causes an increase in traffic volumes in the short term. An approximation of travel time savings would in this case be the total area A+B. However, if we do not take the effect of induced traffic into account we end up with the approximation A+C instead, which is clearly a much larger estimate.

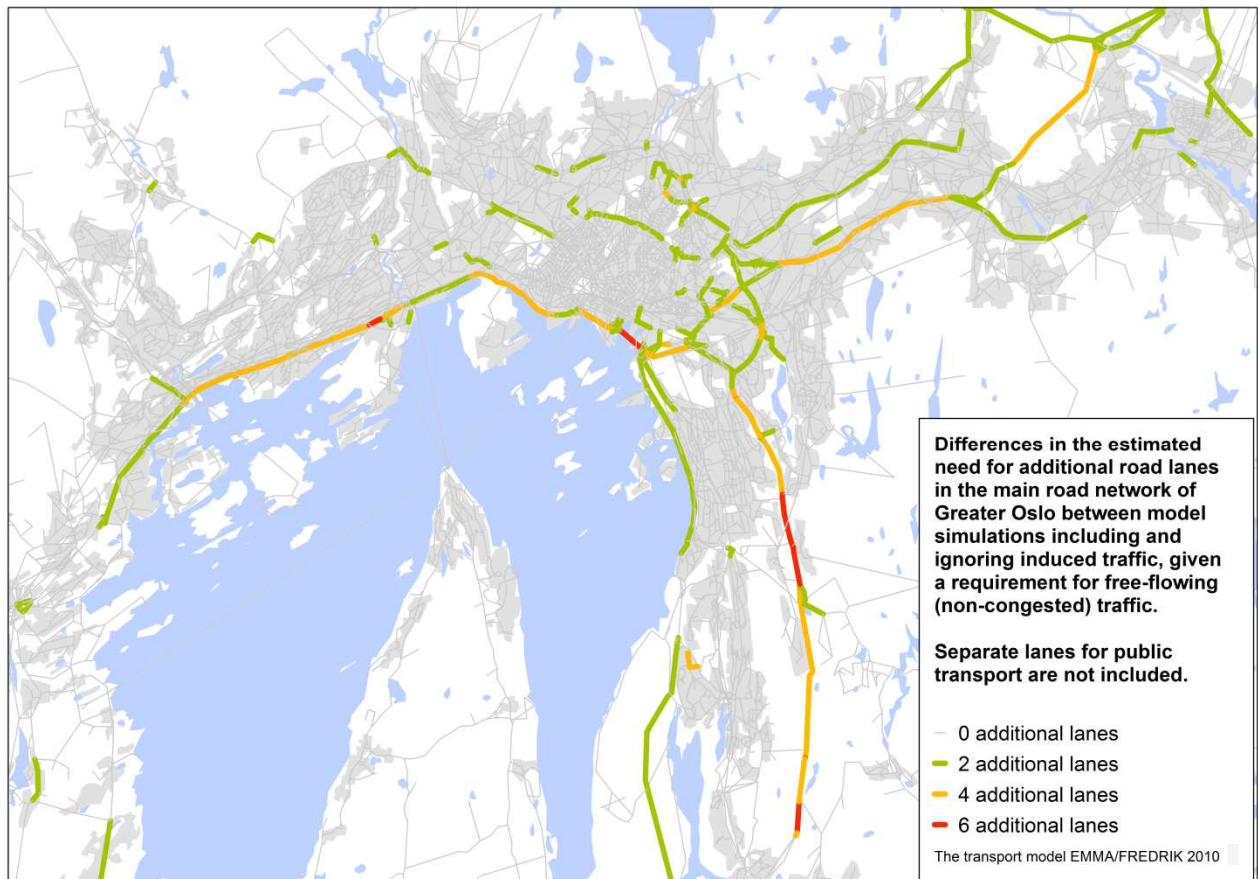


Figure 2. Differences in the estimated need for additional road lanes in the main road network of Greater Oslo between model simulations including and ignoring induced traffic, given a requirement for free-flowing (non-congested) traffic. Source: Simulation made specifically for this article, carried out by Andersen (2011).

It is important to observe that if initial demand is low (i.e. no congestion at X) this effect likely underestimates benefits in the form of travel time savings, as additional drivers would enjoy the benefits without increasing the cost of traffic in any significant way. A Danish example of this could be the new motorways constructed in the northernmost part of Jutland in the years before and after 2000. In such cases the improved road standard usually does not release a large amount of latent demand, and the additional traffic induced by higher speed limits etc. will not be sufficiently great to raise the traffic volume to a level where congestion arises. There are, however, also situations where traffic volumes are high enough that new road capacity can release some demand, but not sufficient to cause immediate congestion problems on the new and expanded road. In such situations, the time savings for new drivers may exceed the increased travel times among existing drivers caused by induced traffic. In addition to our main case

example, we will briefly illustrate such a situation in Section 4, Results. Our main case will, however, be a new road constructed to improve traffic flows in a highly congested urban context. Since capacity expansion is often a measure employed to reduce congestion in areas where this is already a problem or expected to be so in the near future, we consider it highly relevant to illuminate such a situation.

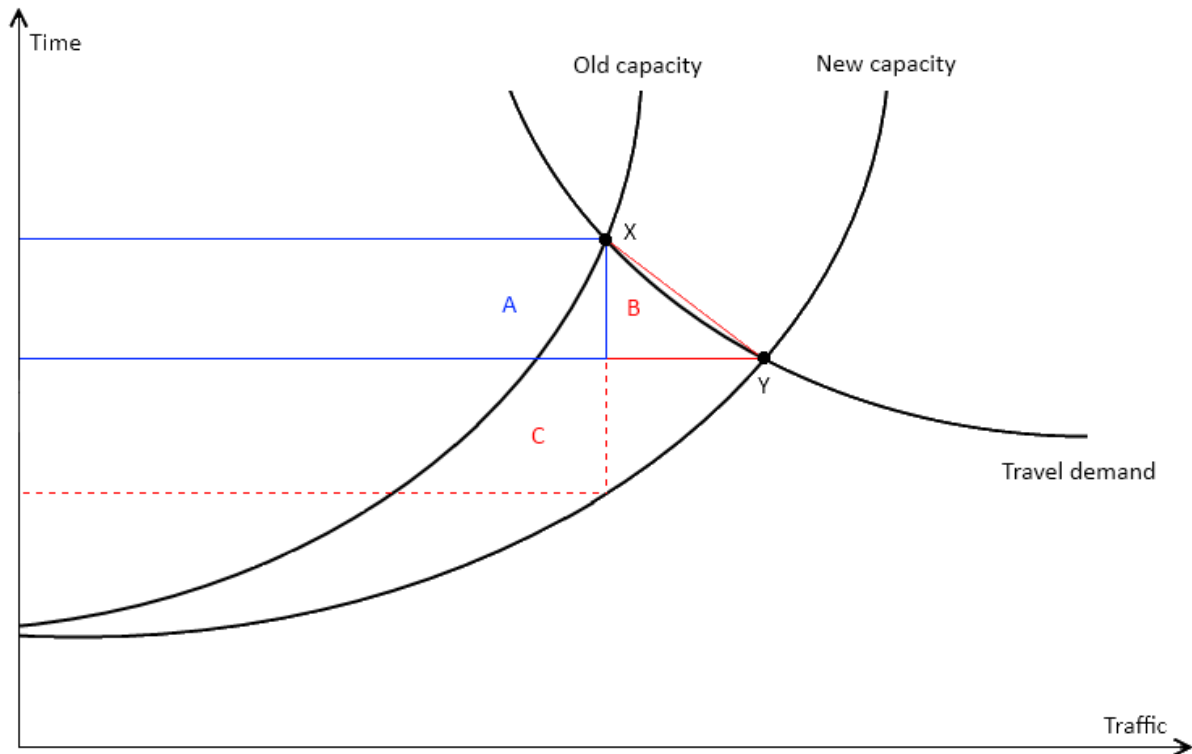


Figure 3. Example of supply and demand curves and time-benefit calculations for a road before and after capacity increase. Adapted from Nielsen and Fosgerau (2005), p. 10.

3. The applied methods in the case example

As transport models are usually built individually for specific geographical regions, it is not trivial to compare the results of CBAs based on forecasts from different models that have either excluded or included the effect of induced traffic. However, this is exactly what has been the goal in the present study, in order to illustrate how neglect of induced traffic can lead to overestimation of benefits. For this purpose we have chosen to perform two appraisals for a selected Danish road project in a congested transport corridor; one which includes induced traffic (model A), and one which does not (model B)⁷. The results will then be compared to see whether inclusion of induced traffic in the transport model will result in a reduction of estimated benefits in a CBA. In order to make the results as representative of a typical appraisal as possible, we have chosen to use a recent road project proposal as our case.

All calculations were performed by the agency that typically handles these tasks in the case area, in order to ensure that the appraisals are as true to standard practice as possible. The consultancy firm Tetraplan was thus hired to do the appraisal. The proposed road link was evaluated using

⁷ In Model A, changes in trip frequency, trip destination, travel mode as well as route choice have been included, whereas in Model B only changes in route choice have been accounted for. The assumed general traffic growth until the year of the forecast (2018) is included in both sets of calculations. (Tetraplan, 2011a.)

current standards for unit prices set by the Danish Ministry of transport. The appraisals with as well as without induced traffic include most of the impact factors included in a standard CBA. However, several effects that could influence the CBA results were excluded due to resource constraints, such as impacts on public transport services or disruptions during construction⁸. However, as construction costs and travel time savings make up the vast majority of total costs and benefits in the CBA for a typical transport project, we doubt that the exclusion of some of the minor effects can have resulted in any substantial misrepresentation of the appraisals presented in the present article. The consequence in the present appraisal is a slight underestimation of costs, which is reflected in higher net present values for both models than would otherwise be the case.

As the transport model did not have the ability to simply switch off the feature used to model induced traffic, we have had to negotiate with the responsible consultant on how to customize the settings of a model to reflect both inclusion and exclusion of induced demand. In the chosen case the OTM model (version 5.2) has been used for this purpose, as it is the only model used in practise in Denmark that has the ability to model induced traffic to the extent necessary for this study. It is a state-of-the-art tour-based demand model at the tactical/operational level, and has several sub-models for predicting the traffic demand for different traffic modes based on different traffic purposes. It should be noted here that the OTM model only models the short-term effects of induced traffic, and the results should therefore be considered highly conservative estimates of the impact of including vs. ignoring induced traffic on appraisal results. The standard OTM model will represent model A. A modified version, which performs like the simpler models typically used in practice, will represent model B. For details on the differences between the two models we refer to Tetraplan (2011a).

The selected case is Nordhavnsvej, which is a planned road project in the northern part of Copenhagen (see figure 4). The new road is intended as congestion relief for the dense residential streets in the nearby Østerbro area just south of the new route. This is argued to be a consequence of comprehensive plans for new urban development in the Nordhavn area just east of the new route, which is expected to house 80,000 new residents and jobs (Municipality of Copenhagen, 2009). These plans are of course expected to increase traffic demand significantly, and the case seems well suited to illustrate the effect of induced traffic on appraisal results for a capacity expansion on a congested network. The current plans for the road involve a new urban link of 1650 metres, with two lanes in each direction and a speed limit of 60 km/h. About 620 metres will be done as a cut-and-cover tunnel, with open ramps in each end. It is expected to reduce traffic in the Østerbro area with 15 % and is set to open in 2015.



Figure 4. The proposed new Nordhavnsvej link in Copenhagen. Legend: Black line: surface road; black dotted line: road tunnel; blue line: surface ramps. Source: Municipality of Copenhagen (2011).

⁸ In an earlier appraisal of the same case, disruption effects amounted to only 6.5 % of construction costs (Rambøll 2008), and since they must be expected to be more or less the same regardless of the transport model used to assess the benefits, it would only serve to increase total costs in both appraisals.

In addition to the full case study we have, as mentioned earlier, also made simulation of a road project on a network with little congestion. The extent of this appraisal was more limited than for the full case study, as only first year benefits were calculated. The purpose of this additional study was mainly to confirm that the induced traffic effect is less important to the CBA results under conditions of low congestion, which also turned out to be the case. More information on this appraisal can be found in Tetraplan (2011b).

4. Results

The overall findings of the Nordhavnsvej case are summarized in Table 1. Although a considerably higher traffic volume could be expected in model A as a result of induced traffic, the difference is only around 5 % compared to model B. Seen in the light of a range of international studies estimating a 10 % capacity increase to result in 3-5 % short-term increase in traffic volumes (Duranton and Turner, 2011; Hansen and Huang, 1997; Litman and Colman, 2001; Noland and Lem, 2002; Strand et al., 2009), the results of model A appear to be in the low range of potential short-term traffic growth. After all, the new link will tie together a four lane motorway with a large redeveloped urban area, where the existing network requires traffic between these destinations to go through dense residential areas. However, in the Nordhavnsvej case, the congestion level is at the outset so high (close to capacity limits) that even a moderate additional traffic can cause substantial reduction in travel speeds. In such a situation, the so-called Braess' paradox may occur, where road capacity increase contributes to reduce overall travel speeds in the network instead of increasing them (Nielsen & Landex, 2005). Since the induced traffic reduces the improvement in travel speeds on Nordhavnsvej considerably, the road's ability to attract additional traffic increase will be constrained. The magnitude of induced traffic will therefore be lower than in a situation where there is considerable congestion but where the capacity increase is large enough to allow for all latent demand to be met without reaching capacity limits.

Table 1. Estimated main traffic-related impacts of the proposed Nordhavnsvej, based on transport model forecasts with induced traffic included (Model A) and ignored (Model B). Source: Tetraplan (2011a).

Impact factor	Model A	Model B
AADT on main link	22,820	21,740
Total travel time savings (mil. DKK)	2,749	4,589
Changes in fuel consumption (tons)	483	-284
Changes in CO ₂ emissions (tons)	1,525	-897
Changes in noise level (weighted score ⁹)	167	162
Changes in safety (accidents involving personal injury)	-0.3	-1.2
Net present value (mil. DKK)	403	2,157
Internal rate of return (%)	5.6	8.1
Benefit ratio per invested capital unit	0.2	1.1

The increased traffic volume in model A results in higher estimates for all environmental cost categories than in model B, although the differences are fairly small compared to the total impact of these factors. An interesting observation is that model B gives the impression that CO₂

⁹ The weighted score is expressed as SBT (støjbelastningstal), which is a standard unit in Danish noise evaluations. A higher score indicates a higher noise level, although in this case the difference is fairly insignificant.

emission levels will drop as a result of increasing capacity. When the effects of induced traffic are taken into account however, the increased emission levels as a result of higher traffic volumes show up correctly in the appraisal, and model A gives a picture that fits much better with the impacts we would expect for this type of project. A similar issue can be observed for traffic accidents, where the benefits calculated in model B are four times larger than in model A. While the absolute figures might appear small, the unit values for accidents are quite high, and the monetized impacts over the lifespan of the project measure in hundreds of millions.

It should be noted that the non-monetized values are only for the opening year of 2015, and that long-term effects must be expected to widen this gap – at least if further capacity increases are made allowing traffic to grow beyond the capacity limits soon reached after the initial road construction. In the simulation, traffic is expected to increase by an additional 10 % towards 2030, but from this point on the traffic level is considered static. Both of these assumptions could be expected to underestimate future traffic levels (at least unless policies to limit traffic growth are introduced, including non-expansion of road capacity), and the results of the appraisal must therefore be considered conservative. This becomes especially important when evaluating the travel time savings calculated on the basis of these traffic volumes, as benefits for the entire 50 year period used in the CBA are likely to be overestimated as a result (even in model A).

Even with all these reservations in mind it should be clear from the results in Table 1 that there is a significant reduction in benefits when the effects of induced traffic are taken into account. The results in Table 2 give a better understanding of why we observe reduced travel time savings when including the effects of induced traffic. In line with the underlying economic theory presented in section 2, we observe positive travel time savings from additional drivers benefiting from the new capacity when we include induced traffic. These benefits correspond to area B in Figure 3. However, it is clearly evident from Table 2 that the benefits from these additional drivers are far too small to offset the loss of benefits to existing drivers, which corresponds to area C in Figure 3.

Table 2. Estimated travel time savings from the proposed Nordhavnsvej, based on transport model forecasts with induced traffic included (Model A) and ignored (Model B). Source: Tetraplan (2011a).

Travel time savings (hours per weekday)	Model A	Model B	Change
Cars			
Existing drivers	834	1282	448
New drivers	37	0	-37
Trucks			
Existing drivers	207	284	77
New drivers	6	0	-6
Travel time savings in congestion (hours per weekday)			
Cars			
Existing drivers	435	874	439
New drivers	16	0	-16
Trucks			
Existing drivers	85	163	78
New drivers	1	0	-1

The above-mentioned effects are the results of quite elementary relationships between supply and demand, but they are often ignored in performance evaluations of demand forecasts. For example, Flyvbjerg et al. (2005) observe that while rail demand is typically greatly overestimated, the trend for road demand seems to be a slight underestimation. They therefore conclude that the problems associated with forecasting benefits are much greater for rail projects than for road projects, which also seem plausible when you only look at the actual traffic volumes. However, as

the results of the present study clearly show, even slight underestimations of traffic volumes on roads can lead to quite significant benefit shortfalls within the CBA framework. In the Nordhavnsvej case a 5 % increase in traffic results in a time-savings loss of 40 %. Since these effects usually make up 80 % or more of the total benefits, this implies that actual benefits are less than 70 % of those expected from the CBA. Depending on the total cost of the project, these benefit shortfalls could potentially make or break the assessment results for a project, and with cost overruns being common it is not unlikely that the internal rate of return could suddenly drop below the standard discount rate. In fact, the present Danish case is quite close to doing so, and had our estimates not been so conservative it might have been dismissed as a non-feasible project in an investment prioritization.

As mentioned earlier, we have also carried out a simulation for a planned motorway in a less congested part of Copenhagen Metropolitan Area. In this case (the so-called Frederikssund motorway leading from one of the outer-area towns to the outskirts of the continuous urban area of Copenhagen), the percentage of traffic growth resulting from induced traffic was higher (around 10-11 %) than in the Nordhavnsvej case (5%). However, due to the much lower congestion level at the outset, the traffic increase in the Frederikssund motorway due to induced traffic would not bring congestion up to a level resulting in significant difference in travel time savings between the models with and without inclusion of induced traffic. Travel time savings were estimated to be 2.7% lower in the simulation with induced traffic than in the model where such traffic growth is ignored, and the benefits due to accident reductions were assessed to be 19% lower. Total travelers' benefits were estimated to be 3.5% lower in the model including induced traffic than in the model omitting induced traffic. (Tetraplan, 2011b).

Although the analysis of the Frederikssund motorway did not show significant congestion arising as a result of induced travel, the 10-11% increase in traffic obviously implies that the time at which the general, 'background' traffic growth causes the traffic volume to approach capacity limits will be shorter than in the absence of induced traffic. As mentioned earlier, only first-year benefits were calculated for the Frederikssund motorway case. Within a longer time horizon, say 15 years, the induced traffic might make up the increment making the difference between severe congestion and high capacity utilization still below capacity limits. With such a time horizon, the difference between the two models in travel time savings would probably have been more similar to that of the Nordhavnsvej case. Or conversely: additional lanes would have to be added several years earlier in order to maintain relatively free-flowing traffic than indicated by the model ignoring induced traffic (cf. also the Oslo example shown in Figure 2).

5. Discussion

The simulations for the Nordhavnsvej project illustrate the point made by Litman (2011) that a small amount of induced traffic can have a disproportionately large effect on the cost effectiveness of a road project. This is especially so in congested transport corridors, because of non-linear speed flow relationships and typically small net differences between large costs and large benefits. In such situations, underestimation of traffic demand resulting from failure to take induced traffic into account results in appraisals that, *ceteris paribus*, favour capacity expansion to a larger degree than if this effect is accounted for. The effect is especially crucial in the calculation of travel time savings, as the increased traffic volumes eat up much of the expected utility gains from capacity expansions. There might be a larger total number of drivers benefiting from the new capacity, but the benefit per driver is significantly reduced due to congestion forming much earlier than anticipated.

In the short term the extra traffic leads to benefit shortfalls in the form of longer travel times, which is problematic for the validity of appraisals (particularly CBAs). In the long term it leads to even further benefit shortfalls for time savings, but also severe underestimation of the adverse

environmental effects of facilitating continued growth in urban vehicle traffic. As many of these effects are not included in the present study, we cannot give any quantitative estimate on the extent of these consequences. Constructing a study able to make valid conclusions on these matters is far beyond the scope of the present article, and any attempt at doing so is bound to involve considerable leaps of faith due to the number of causal mechanisms at work in open systems such as these. In addition to the environmental problems are other long-term effects of road capacity expansions that it has not been possible to cover in the present study, such as increased car ownership, long-term changes in commute patterns and land use, and deteriorating effects on the relative attractiveness of public transport options, as well as their financial viability from a reduced customer base.

It is important to note that the issues raised in the present article do not mean that there are no benefits to gain from expanding road capacity in congested urban areas, as more capacity will always offer some form of benefit for drivers. If nothing else, it creates the ability for more traffic to flow through the network. What we argue here is simply that the costs of providing this increased capacity are underestimated and the benefits exaggerated when traffic volumes are underestimated, by ignoring the loss of time savings and increased environmental costs. As a consequence, appraisals of capacity expansion picture such projects as better investments than is actually the case, which likely results in them being prioritized to a larger extent than they would be if the costs and benefits had been more adequately assessed.

The practice of CBA of infrastructure projects has hardly been introduced in order to increase the overall spending on road infrastructure. Rather, it could be interpreted as part of a neoclassical economical paradigm (Ackerman and Heinzerling 2004; Mackie 2010) favoured by the currently dominant neoliberal political climate. However, since such analyses are mandatory in most European countries, systematic bias in their appraisal becomes a fundamental democratic problem. They serve to legitimize a higher spending on road construction in congested urban contexts than what would otherwise be the case, and arguably increases the possibility for lobbyists in favour of capacity expansions to set the political agenda.

Yet, the frequent use of transport models that ignore induced traffic does not seem to have created any widespread denial among decision-makers of the fact that this effect is a likely consequence of road construction. In a survey of 453 Danish, Norwegian, and Swedish stakeholders involved in decision-making on larger transport infrastructure projects, the respondents were asked whether they agreed with the statement that expansion of road capacity results in an overall increase in traffic (UNITE, 2011b). In a standard five point Likert-scale response format (1=disagree, 5=agree), politicians scored an average of 3.64, indicating that the majority of them acknowledge this effect. However, politicians were still the most sceptical of all respondents, with consultants (4.41) and researchers (4.36) scoring much higher¹⁰. The fact that politicians are aware of induced traffic does not necessarily imply that the consequences for appraisal are consistently addressed. The model results can be used selectively depending on the issues at stake and their corresponding criteria for successful negotiation strategies, where forecasts showing a higher growth in traffic will be given more attention when this is desirable and less attention when this is not the case. In our interviews, one of the members of the Danish parliamentary transport committee gave the following account of the issue in relation to a proposed toll financed project, where the desirable traffic volume depended on changing criteria for assessment (UNITE, 2011a):

“You can find yourself in the somewhat paradoxical situation that we are much aware of induced traffic when the economic arguments for investment are shaky. We had some fun with the Fehmarn Belt Fixed Link, as it was clear that we would account for induced traffic; otherwise the economy of the project would fail. On

¹⁰ Both one-way ANOVA and Kruskal-Wallis tests of these results showed statistical significance at the 0.05 level.

the other hand, we were not so much in favour of it when the environmental assessments were to be made [...] obviously there is a large degree of freedom associated with these things"

Danish Member of Parliament in the Transport Committee

Several studies have shown that the transport infrastructure project proposals chosen for implementation are not necessarily those that are rated highest in CBAs. This has been documented in Norway (Nyborg and Spangen, 1996; Fridstrøm and Elvik, 1997; Sager and Ravlum, 2005; Odeck, 2010), Sweden (Eliasson and Lundberg, 2010) as well as in Denmark (Rothenborg, 2006; Simonsen, 2002). There also seems to be a tendency among politicians of prioritizing among road projects and rail projects separately (Nyborg and Spangen, 1996; Langmyhr, 2001). CBAs of individual road and rail projects thus do not appear to compete directly for funds in either Denmark or Norway, but the appraisals can of course still exercise an influence on the initial prioritization between the two sectors. In these cases it would be problematic if appraisals for one type of projects continually outperform those of the other by a large margin due to faulty appraisal techniques, even if the projects are not compared directly and only partly influenced by the result of CBAs. Moreover, benefit exaggeration for a large number of projects could result in an overall overinvestment in transport infrastructure, with less money left for other kinds of public spending like health care, education, etc. (Boarnet, 1995; Litman, 2011).

In the contemporary political context of the Nordic countries, economic arguments are perhaps not the most important ones when debating whether or not to implement major road construction schemes. Especially in the urban regions, opposition against such projects is often founded on environmental concerns. Here, model predictions that ignore induced traffic tend to underestimate the impacts of road capacity on energy consumption, emissions, noise, as well as injuries and deaths caused by traffic accidents. This applies to individual projects, larger strategic plans, as well as the overall discourse on the most suitable approach to solving transport related problems in society. The message from such analyses is clear: The claim that road capacity expansion will lead to negative traffic-related environmental impacts is unfounded.

For example, in a report from the Norwegian research and consultancy company SINTEF, the authors concluded, based on micro-simulations, that better roads in terms of alignment, sufficient width and capacity, which give the traffic the possibility to flow steadily, lead to less emission from car traffic and are regarded as a positive contribution to a sustainable environment. Moreover, according to the authors, restraining the capacity in the road network is an environmentally unsound measure to promote lower emission from road traffic (Knudsen and Bang, 2007). In Denmark, several environmental impact assessments of proposed road building projects have likewise concluded that the impacts of the projects to energy use and CO₂ emissions will be negligible and the consequences in terms of noise and accidents positive. In some cases, like the 2006 environmental impact assessment of the proposed Third Limfjord Crossing near Aalborg, the analysis predicts, in line with the SINTEF report, that the construction of a new motorway bypass road will reduce energy consumption and greenhouse gas emissions, alleviate noise, and help combatting traffic injuries and deaths (Næss, 2011). A newer assessment for the same project reaches the similar conclusions (Danish Road Directorate, 2011), and while it claims to account for induced traffic, the elasticity value used to do so seems remarkably low. The proposed project will add two new motorway lanes in each direction over a small sound in a congested area, where the existing capacity is only five lanes in each direction (three of which are motorway lanes). Yet, the report concludes that the induced traffic will be less than 0.4 %, which must be considered extremely conservative when compared to several international studies on the connection between new motorway capacity and induced traffic, which estimate elasticity to be in the 0.3-0.6 range (Cervero and Hansen, 2002; Duranton and Turner, 2011; Goodwin, 1996; Hansen and Huang, 1997; Litman and Colman, 2001; Noland and Lem, 2002; Strand et al., 2009).

Considering the typical underestimation of traffic demand for roads that has been common in Denmark (Holm, 2000), we find induced traffic in the environmental impact assessment to be considerably underestimated.

An important effect of transport model calculations ignoring induced traffic can thus be to disarm environmental opposition against a project, whether intentional or not. Given the black-boxed nature of model-based traffic forecasts, it is difficult for actors outside the community of modellers to question the correctness of the results. Most transport models are simply far too complex for outsiders to assess whether the results have been produced in a way that best depicts the likely consequences of a proposed project. Even if this were not the case, most decision-makers probably care little about the underlying procedures that modellers employ in their work, as they are mainly concerned with the outcome and tend to be far too busy to engage in specialized technicalities even if they had the ability to do so. The models are therefore often regarded as truth-production technologies (Ackerman, 2008; Henman, 2002), and can by virtue of that play an important role in power struggles over how to conceive of a problem and its solutions. This does not mean that their results are always taken at face value however, since mistrust of them is common when the appraisal methodology is not understood by those using them for decision support, or when inclusion of less tangible effects of great importance is poor (Beukers, Bertolini, and Brömmelstroet, 2012).

Whatever the reason may be for not taking induced traffic into account, one of the immediate consequences is a systematic overestimation of benefits in the form of travel time savings. In addition to this comes the increased environmental cost of higher traffic volumes. Since future traffic volumes are usually estimated on the basis of trend extrapolation, the neglect of induced traffic might also cause an overestimation of demand in the case where no new capacity is added (Næss, 2011). The observed trends in traffic growth are themselves partly a result of prior capacity expansions, and a deliberate choice to abstain from this predict-and-provide approach is likely to result in lower traffic growth than in a business-as-usual scenario. By ignoring induced traffic the deterrent effects of congestion on future traffic growth for the zero-alternatives is thereby also ignored, and since these are the baseline with which different alternatives are compared, this causes further overestimation of benefits from capacity expansion. The magnitude of this latter error cannot be measured by simply comparing forecasted traffic volumes on new roads with actual traffic counts, since the traffic development in the no-build situation represents a counterfactual scenario. The typical performance evaluation approach applied by Flyvbjerg et al., Holm, Odeck, Parthasarathi and Levinson, and others to assess benefit shortfall for road projects is therefore insufficient to assess this type of inaccuracy. The learning potential from investigating these matters further seems quite abundant, and should probably be explored in future studies of uncertainty in transport appraisal.

6. Concluding remarks

The results presented in section 4 clearly show a significant overestimation of benefits in appraisals that fail to account for induced demand. Once again, we would like to emphasize that these results are only an expression of the short-term effects that result from induced demand, and that long term effects must be expected to increase these exponentially. Furthermore, the faulty conclusions that decision-makers might derive from such appraisals can create a positive feedback loop of continued capacity expansions that do little to solve congestion in practice. Instead, such appraisals create an artificial demand for further capacity expansions, since the expansions themselves create much of the demand that is later extrapolated to reflect a 'natural' traffic growth for which capacity must be provided.

Although model-based forecasts, and the cost-benefit analyses in which they are used, do not influence decisions about project implementation in a one-to-one manner, a systematic

overestimation of benefits and underestimation of adverse environmental effects generally tend to legitimize a high spending of society's resources on road construction. They also tend to delegitimize environmental opposition and disarm environmentalists of their arguments. Motorway construction can thus be supported by transport model forecasts ignoring induced traffic, and it is even portrayed as a suitable approach to reduce greenhouse gas emissions.

The technical complexity and lack of transparency is a hindrance to outside peer-review of model results, which allows actors with expert knowledge to exercise great power on the decision-making process, whether intentional or not. As the full effect of induced demand is no trivial matter to include in demand modelling, it is often left out or only partially included in the technical analysis feeding into project appraisal. Decision-makers who are unaware of this can easily be led to make the wrong conclusions about the consequences of their actions, while decision-makers who are aware of it can use the black-boxing effect to their advantage by promoting their own interest under the guise of objective assessment criteria.

Due to the considerable difficulty in knowing beforehand how large the elasticity between road capacity increase and traffic growth will be in a particular transport corridor at a particular time, there is an inherent non-exactness of forecasts of differences between 'do something' and 'do nothing' (Næss and Strand, 2012). In cost-benefit analysis, uncertainty and controversy about how to assess the monetary value of travel time savings (Nicolaisen and Næss, 2011) as well as environmental impacts add to the overall uncertainty of the method. Cost-benefit analysis, which requires precise quantitative input, is therefore in our view not appropriate for assessing whether or not to build a proposed project of a particular category (e.g. a road project) in a specific geographic context. It may, however, be less inappropriate if the task is to compare different alternative ways of designing this project (e.g. layout A, layout B or layout C for a proposed new road). However, due to the uncertainty mentioned above, the CBA should then only be used to assess the marginal differences between different variants of the project, not its absolute economic value.

Given the problematic issues associated with current appraisal practice we argue that it would be more fruitful to pursue a more holistic appraisal approach with simpler, theory-informed models based on multiple scenarios for input variables and more comprehensive sensitivity analyses, rather than pretending to calculate the exact implications of projects. Due to the long timeframes involved in transport planning, we might be better off acknowledging that we will probably never be able to produce very accurate forecasts. The fixation with model calibrations for monetized quantification seems to push common sense in the background, and since the technical deficiencies of black-boxed models can produce results with severe bias, we should perhaps focus on more transparent approaches for the appraisal techniques used in the initial scoping and selection of projects. In this context it is perhaps no wonder that results of technical analysis are at times viewed with some disdain by decision-makers. Not because they lack in their ability provide useful insights, but because it is easy to abuse the tools by using them to solve problems they are ill suited at addressing.

The more holistic approach suggested above does not square well with the function of model-based traffic forecasts as quantified inputs to cost-benefit analyses in their current form, since this requires forecasts to be extremely accurate. But are forecasts really accurate enough to determine whether commuters will save e.g. 2.15 or 3.12 minutes on average from a new link? Many other public-sector branches use this evaluation method to a much lesser extent, based on the rationality that the effects cannot be quantified to a desirable degree. In addition, after the projects have been completed there are rarely ex-post evaluations of whether the expected goals were met, which would seem a requirement to monitor effective allocation of funds if this is really of such key importance. When cost-benefit methodology builds on such uncertain premises as displayed in the present article, decision-makers should at least take the results with a large grain of salt when considering conceptually different solutions (e.g. investing in road projects,

public transport solutions, travel demand management initiatives, or doing nothing at all). If the decisions relate to mere design choices of a project that is already decided, cost benefit analysis methodology is likely to be less problematic.

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